Sediment Transport Analysis from OBS/EMCM during Storms

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PURPOSE: The Coastal Engineering Technical Note (CETN) herein provides information and procedures for analyzing instantaneous measurements of currents and suspended sand to estimate longshore sand transport during storms. The information and procedures described in this CETN will assist others in developing similar and improved measurement techniques.

BACKGROUND: Longshore sand transport is a primary factor in many coastal engineering studies and influences coastal erosion, impoundment at structures, channel infilling, and morphological behavior of ebb shoals, spits, and capes. A significant portion of longshore sediment transport occurs during coastal storms. To quantify and characterize longshore transport induced by the combined influences of waves and currents, the Sediment Transport Processes (STORM) Work Unit has measured currents and instantaneous concentration of suspended sand across the surf zone during storms.

The STORM data referenced in this CETN were collected during an extratropical event at Duck, NC in October 1997. Data were collected using the Sensor Insertion System (SIS), which is a crane that moves along the pier at the U.S. Army Corps of Engineers Field Research Facility (Miller 1999). This system provides the opportunity to place an instrument array at any cross-shore location at approximately 20 m updrift of the pier pilings. Instrumentation on the SIS included optical backscatter sensors (OBS) for measuring sand concentration, electromagnetic current meters (EMCM) for measuring current velocity, a sonic altimeter for referencing instrument location relative to the bottom, and a pressure sensor for measuring water depth. Positioning of instruments, methods of data collection, and procedures for analysis of measurements are critical for accurate estimates of longshore transport.

After data collection, concentration and velocity data are analyzed, the water column is discretized into vertical bins with representative velocity and concentration values, and unit transport is estimated. If sufficient cross-shore stations have been measured, total longshore transport can be estimated from the cross-shore distribution of unit transport.

MEASUREMENTS: Velocity and concentration in the surf zone may change significantly both spatially and temporally. To appropriately estimate longshore transport, the spatial and temporal variability of these parameters must be considered.

Sand concentration and velocity variations occur on a relatively large scale in the cross-shore direction. Longshore transport in the swash zone may vary significantly on the order of meters or less, while in the surf zone significant variation may occur on the order of tens of meters or more. Transport during storms may vary significantly between the regions of the nearshore: swash zone, surf zone inshore of the trough, the trough, the bar, and offshore of the bar. Transport within each of these regions must be accurately defined to estimate total longshore

transport. The required number of sampling locations depends on the site-specific conditions and the beach profile. Figure 1 shows an example of cross-shore locations sampled during the October 1997 extra-tropical storm studied as part of the STORM experiments.
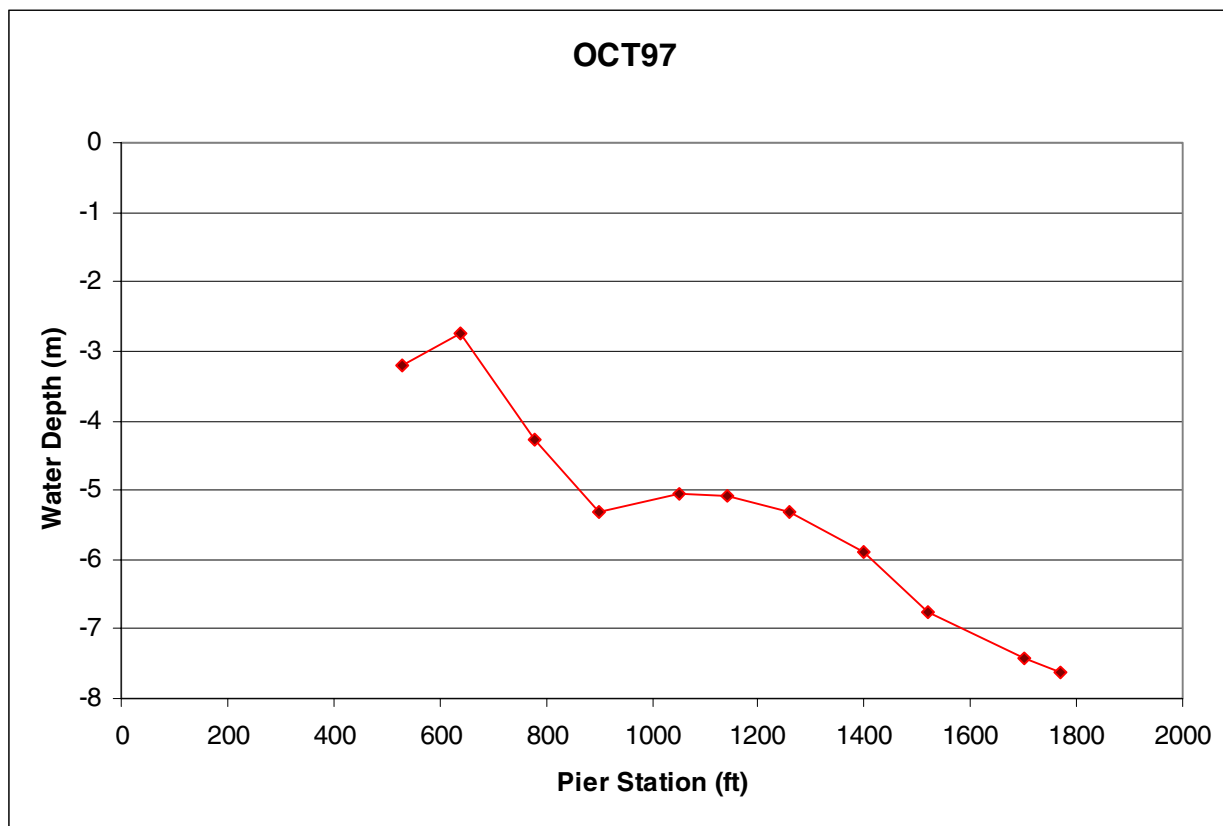

Figure 1. Example cross-shore depth and sampling locations for the October 1997 STORM experiments (to convert feet to meters, multiply by 0.3048)

Spatial variation of transport processes occurs on a much smaller scale in the vertical direction. Large vertical gradients in concentration, as shown in Figure 2, require closely spaced measurements of concentration near the bed, with increasing instrument spacing higher in the water column. Vertical distribution of instruments deployed during the STORM experiments is illustrated in Figure 3.

Bed-load transport, which occurs near the sediment/water interface, is one of the most difficult to identify and measure. The dynamics of this very thin layer of moving sediment are likely to be significantly altered by the presence of instrumentation. In most cases, the SIS instrumentation is located above the layer of bed-load movement, and consequently the estimates of transport should be considered suspended load only.
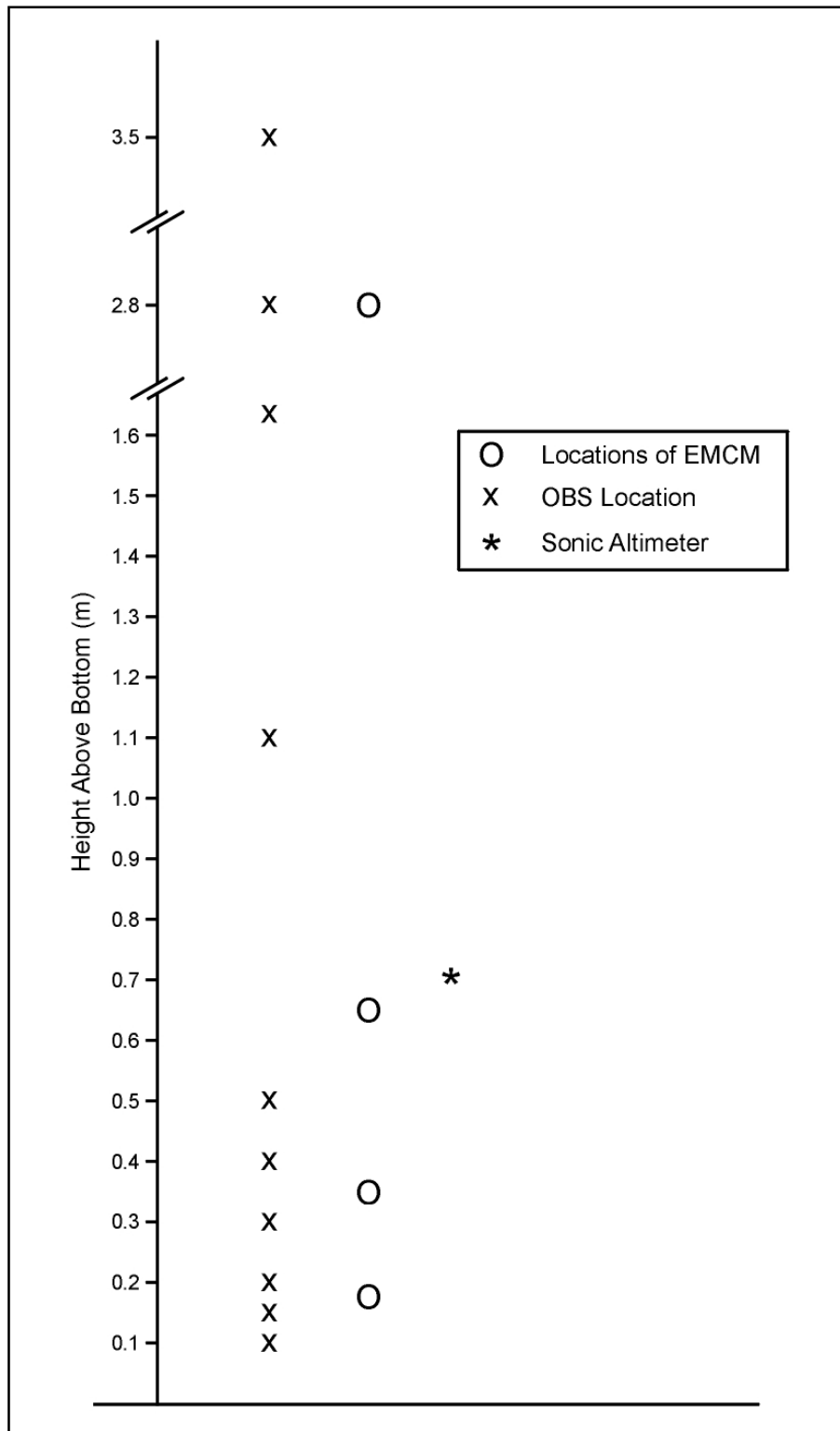
Figure 2. Vertical distribution of instruments
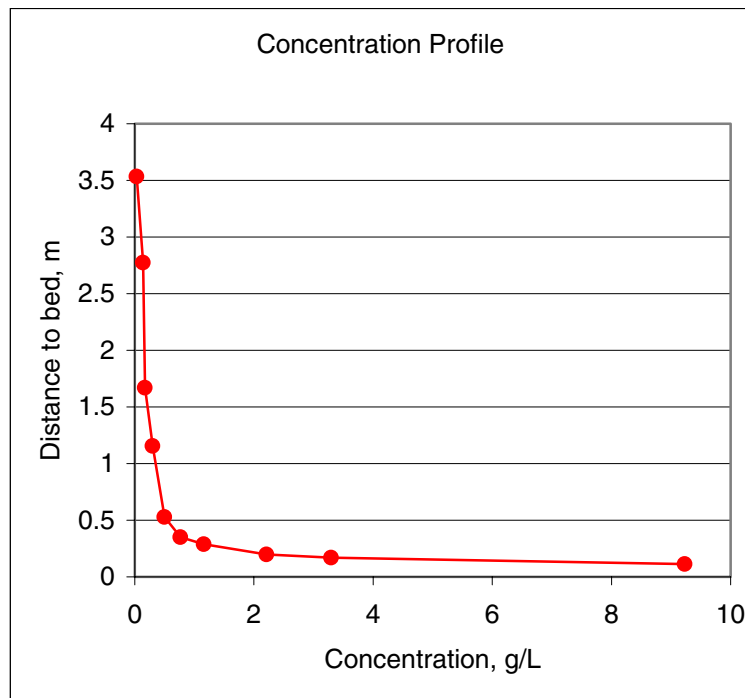during the STORM experiments

Figure 3. Example concentration profile from October
1997 STORM experiment

Temporal variation of sand concentration and orbital velocity occurs on short time scales, at a small fraction of a wave period. Sand concentrations peak with the passage of each wave cycle, sometimes changing from near zero to several hundred mg/L and back to near zero during a half wave cycle. Current direction and magnitude also change continually through a wave cycle, reversing direction and reaching a maximum every half cycle. To resolve the transport of suspended sand by orbital wave motion, both sand concentration and orbital velocity must be sampled at high frequency, typically at greater than 2 Hz.

Without the deployment of multiple instrument arrays, measuring across the nearshore requires several hours to collect data at each station and to move from one station to the next. Fortunately, wave and current conditions during a storm are generally quasi-steady over the period of an hour or more. However, tidal currents and elevations at midtide may be significant at the time scale of an hour. To minimize tidal variations, data collection across the surf zone was limited to the periods of high and low tide, when tidal currents and elevations change minimally.

EQUIPMENT: The instruments described in this section were used during the STORM experiments. Other instruments are available to measure the same quantities. The primary sensors for measuring sediment flux are a vertical array of OBS (Downing, Sternberg, and Lister 1981) or other instrument to measure sediment concentration and electromagnetic current meters (EMCM) or other instrument to measure flow velocities. An example of a vertical array used in the October 1997 STORM experiments is shown in Figure 3. This array consisted of 10 OBS and four EMCMs attached updrift of a support frame. The OBS are vertically distributed so that most of the sensors are positioned within 1.0 m of the ocean bottom. The four EMCMs are located

near the OBS in the same cross-shore and vertical position so waves reach both sets of instruments at nearly the same phase. For the STORM experiments, all sensors are sampled at 16 Hz. Any experiments should include a similar high frequency for sampling due to the rapidly changing nature of sand concentration and velocity during a storm wave period. Other sensors should include a downward-looking sonic altimeter to provide an estimate of the bed elevation relative to the instruments and a pressure sensor to record local water level fluctuations.

OBS: OBS operate on the principle that concentration can be related to the scattering of a beam of light emitted into the water column. The volume over which the concentration is estimated is on the order of 1 cm^3. As will be described later, OBS measurements must be calibrated for the sediments being measured to avoid incorrect interpretations of the light scattering. Calibration should be performed just prior to measurements to assure reliability. Suspended sediment samples collected during the storm can be used to verify that the composition has not changed from the composition for which the OBS were calibrated.

EMCM: EMCMs measure water velocity by relating water flowing past a sensor to an electromagnetic response of that sensor. This relationship relies on calibration to provide an offset value. If this offset value drifts significantly between calibrations, data quality can be affected. Therefore, the relationship between sensor reading and velocity must be checked periodically. An EMCM has four nodes and measures bidirectional currents, which can be expressed in cross-shore and longshore directions. As will be described later, EMCMs can be affected by interference from other electronic devices and precautions must be undertaken to assure data quality.

Sonic Altimeter: A single sonic altimeter was used during the STORM experiments to identify the location of the sediment bed relative to each instrument. The altimeter emits a 1 MHz acoustic signal sampled at 16 Hz and measures the bottom position from the reflected signal. Although the altimeter or other interface-detecting instruments operate fairly well during storm periods, the interface may not be detectable during the most high-energy periods, particularly in the area near the swash zone. The sediment bed/water interface becomes less defined during high-energy periods due to fluidization and sheet flow movement, which may make it difficult to define an interface. In addition, air bubbles between the altimeter and the bed will result in false echoes.

DATA PROCESSING: Processing, analysis, and evaluation of the collected data must be performed to ensure correct estimates of sediment transport. Processing of OBS, EMCM, and altimeter data are described in this section.

Processing of OBS Signals: OBS measure the reflection of emitted radiation from suspended solids in the water column, regardless of the source of reflection (sand, fine particles, organic material, biological fouling, aquatic organisms, etc.). Assuming that fine particles that result in turbidity are well mixed and do not settle rapidly and that sand particles are suspended and settle out intermittently, a defined level of background turbidity can be established and subtracted from the indicated OBS signal (Beach and Sternberg 1988). The method for estimating the background turbidity involves the application of a moving window for which a 10th percentile value of OBS signal is determined. This 10th percentile represents the concentration for which

10 percent of the concentration measurements within the window limits are less than. The 10th percentile concentration, or the background turbidity, is then subtracted from the signal to provide a concentration that is assumed to represent the concentration of sand in the water column.

As with the EMCM, the OBS must be regularly calibrated to assure data quality. Calibration is provided by measuring OBS response to a known quantity of sand well mixed into a known quantity of water. One shortcoming of OBS is that they are calibrated to a known grain size distribution (usually sediment collected from the location where measurements are made). Different sizes and shapes of material will scatter light differently. This will cause drift in signals if the grain size distribution changes during deployment. This is a problem when measuring along a cross-shore transect during storms because the material will be sorted during the storm, leaving more coarse grain material in the nearshore and finer material offshore. For example, it is known that fine particles, which tend to have larger surface area to mass ratios than sands, will exaggerate a signal calibrated to fine sand. This causes problems after the offset is removed because the entire signal has been exaggerated, possibly resulting in overestimate of sand concentration. Wherever possible, in situ samples should be collected during deployment to indicate if this situation exists.

During deployment periods, the OBS signal may sometimes contain spurious signals that are not representative of the suspension and settling of sand or have signal magnitudes inconsistent with the forcing conditions measured. Small plumes of fine sediments from other sources, aquatic life, or suspended debris may be explanations for anomalous signals. The OBS signals must be further analyzed after removal of offset values to eliminate signals inconsistent with the suspension of sandy material. Offshore, this can often be done using screening tools, but nearshore, conditions are variable enough that analysis for these spurious signals must be performed visually.

At elevation of approximately 1 m above the sediment bed, there will be minimal sand signal in the OBS time series during storms. OBS exhibiting this behavior should not be included in the longshore transport estimates. Noise remaining after processing to remove background turbidity will dominate these signals and lead to exaggerated transport estimates in the upper water column. In addition, wave movement will result in some upper OBS protruding above the air/water interface during a portion of some deployments. The signals from these OBS are evident by their non-sand nature and should not be used in transport estimates. Buried OBS are evident by their full-scale, flat-line signal. The buried portion of the signal should be omitted from transport estimates.

Processing EMCM Signals: Currents serve to transport suspended sediments and temporal and spatial variations in currents must be defined to accurately quantify the transport of suspended sediments across the surf zone. At a particular data-collection station, a vertical distribution of current meters is used to measure velocity at various elevations above the bed to define spatial variation of current speed in the vertical direction. A high sampling frequency (~16 Hz) is needed to define the temporal variation in the currents. Quality control checks on the collected data are required to ensure that sediment transport is estimated correctly.

Four primary checks must be performed on the EMCM data to ensure that the currents are measured appropriately. These checks include instrument position and orientation, continuous instrument submersion, EMCM offset checks, and checks on electronic noise. Some of these quality-assurance checks may be performed in the field, as data are collected, others may be performed during post-processing of the data. Quality assurance checks during data collection are recommended as these checks may identify an improperly deployed or malfunctioning instrument. Methods for checking EMCM data quality include checks on instrument position and orientation, instrument submersion, offset checks, and electronic noise.

Instrument Position and Orientation: Instrument position and orientation must be verified primarily during data collection. Regular checks of instrument position and orientation during data collection will ensure that the data can be applied appropriately for transport estimates. During post processing, the measured cross-shore current may be compared to the pressure signal to verify the proper instrument position. Assuring that the current direction is properly associated with the wave phase is a fundamental check on proper instrument orientation. Ensuring that longshore currents are consistent through the water column is another useful check on proper instrument orientation that may be performed during post-processing of the data.

Instrument Submersion: To properly operate, the EMCM must be continuously submerged. Intermittent submersion of the instrument (by varying water surface of waves) may cause recorded signals from the instrument to spike erratically and become unreliable, even after the instrument becomes submerged again. Recorded signals of EMCMs that are above the surface or become intermittently wet and dry during data collection are relatively easy to identify. Erratic spikes, uncharacteristic of currents produced by water waves, easily identify the signals of intermittently submerged EMCMs. Instruments located above the water surface typically produce a relatively flat signal that is uncharacteristic of the orbital velocities associated with waves. Signals that appear to be out-of-water or intermittently submerged should be omitted from sediment transport estimates.

Offset Checks: Water velocity can be estimated from a quadratic equation describing the electro-magnetic response of an EMCM to water flowing past its sensors. The response function in the form of $V=mU+b$, relates the signal output (V) to current flowing past an EMCM (U) times the instrument's gain (m) and the instrument's offset (b). The EMCM offset may change with damage to the EMCM nodes, bio-fouling, or other changes to the instrument's configuration. EMCM offsets should be tested periodically by performing an offset check.

Many methods are available to perform offset checks. One method is to deploy the EMCMs into the longshore current and collect data several minutes. After collecting the initial data set, the EMCMs are rotated by 90, 180, and 270 degrees and additional data sets collected. These four data sets are collected over short enough duration to assume that the mean longshore current is relatively constant. Verification that no changes in EMCM offset have occurred is accomplished by comparing the longshore velocities measured by independent channels of the EMCM.

During post-processing, changes in EMCM offset may be evident by comparing the longshore current estimated from EMCMs at various elevations in the water column. An indication that an EMCM offset has changed is if one sensor estimates radically different currents from the other

EMCMs. Indications that the offset of an EMCM has changed may require either the estimation of the new offset from offset checks in the field or omission of the instrument from transport estimates.

Electronic Noise: As the case with many electronic sensors, EMCMs are susceptible to electronic noise. The EMCM is particularly sensitive because the sensor's operating principle requires the measurement of changes in electromagnetic fields. Precautions such as buffer distances between sensors, other instruments, and ferrous metals; shielding of cables; and electronic filters significantly reduce electronic noise recorded by EMCMs. As effective as these precautionary measures are in reducing noise, they are not fail-safe. Under certain conditions, electronic noise may be significant enough to require additional measures in processing the current data.

During the data collection period, monitoring of the real-time signals of the EMCMs may indicate a problem with electronic noise. Signals from the EMCM should be monitored for electronic noise, and if necessary the source of electronic noise should be identified and action taken to reduce the noise if possible.

As part of post-processing of the current data from EMCMs, the analyst should monitor the recorded signals, assess the significance of electronic noise present in the data, and take appropriate action. The source of electronic noise is often a 60 Hz signal from AC power. The electronic noise will not appear as 60 Hz in the collected data if the sampling rate is significantly less than 60 Hz. Instead the electronic noise will appear wrapped into a lower frequency. For example, 60 Hz noise for 16 Hz sampling rate will appear as a peak at 4 Hz. Appropriate action may be in the form of discarding the data or applying filters to the data to reduce the electronic noise and obtain a reasonable signal. Filters will work only in a portion of the spectrum where significant wave energy is absent.

Determining bed location: Estimating the position of sensors above the bed is a fundamental and key action for estimating sediment transport. The sensitivity of transport estimates to the location of the lowest instruments in the water column is related to the fact that the highest suspended sediment concentrations occur near the bed. Bed elevation for the STORM experiments was determined primarily from sonic altimeter. These devices emit acoustic signals that are reflected from the change in the density of the transmitting medium at the sediment bed/water interface. The acoustic sonar performs well when sounding off a hard bottom (with a distinct difference in density at the sediment-water interface) and few bubbles in the water column. (Bubbles tend to scatter the emitted and reflected signal and result in a less distinct reflected signal.)

When the sonar receives a strong reflected signal, a "lock" in the recorded signal is achieved. The locked signal is an indication that the sonar is repeatedly receiving reflected signals from the bottom at a certain distance from the sonar head. By relating the relative position of the sonar head to the other sensors, the distance from each sensor to the bottom is obtained. Interface location data should be analyzed both visually and statistically to accurately measure location of instruments. When estimating transport, errors of only a few centimeters for interface location may result in significant changes in transport rate estimates because the concentrations and transport near bottom will change orders of magnitude within a few centimeters.

In situations where the sonar cannot interpret the reflected signals (typically near shore where bubbles interfere with the acoustic signal) other methods to locate the sediment bed/water interface may be employed. For the STORM experiments, a secondary method for estimating bottom location was by the identification of buried OBS. By identifying the depth of buried OBS, relative distances from the seabed to other instruments could be estimated. In cases where there was no sonar lock and no OBS were buried, sediment transport was not estimated.

VERTICALLY INTEGRATED UNIT TRANSPORT: Discrete values of concentration, elevation, and velocity must be integrated over time and in the vertical direction to provide sediment transport rate per unit width in the longshore direction. One method for performing these calculations is to discretize concentration into individual vertical bins, with bin boundaries located midway between OBS locations. The lower bin bottom boundary will be the sediment bed/water interface and the upper bin top boundary will be the air/water interface. The EMCM, which may or may not correspond to OBS location, can be interpolated to provide a current value for each bin (Figure 4). Any bins where noise dominates the signal should not be included
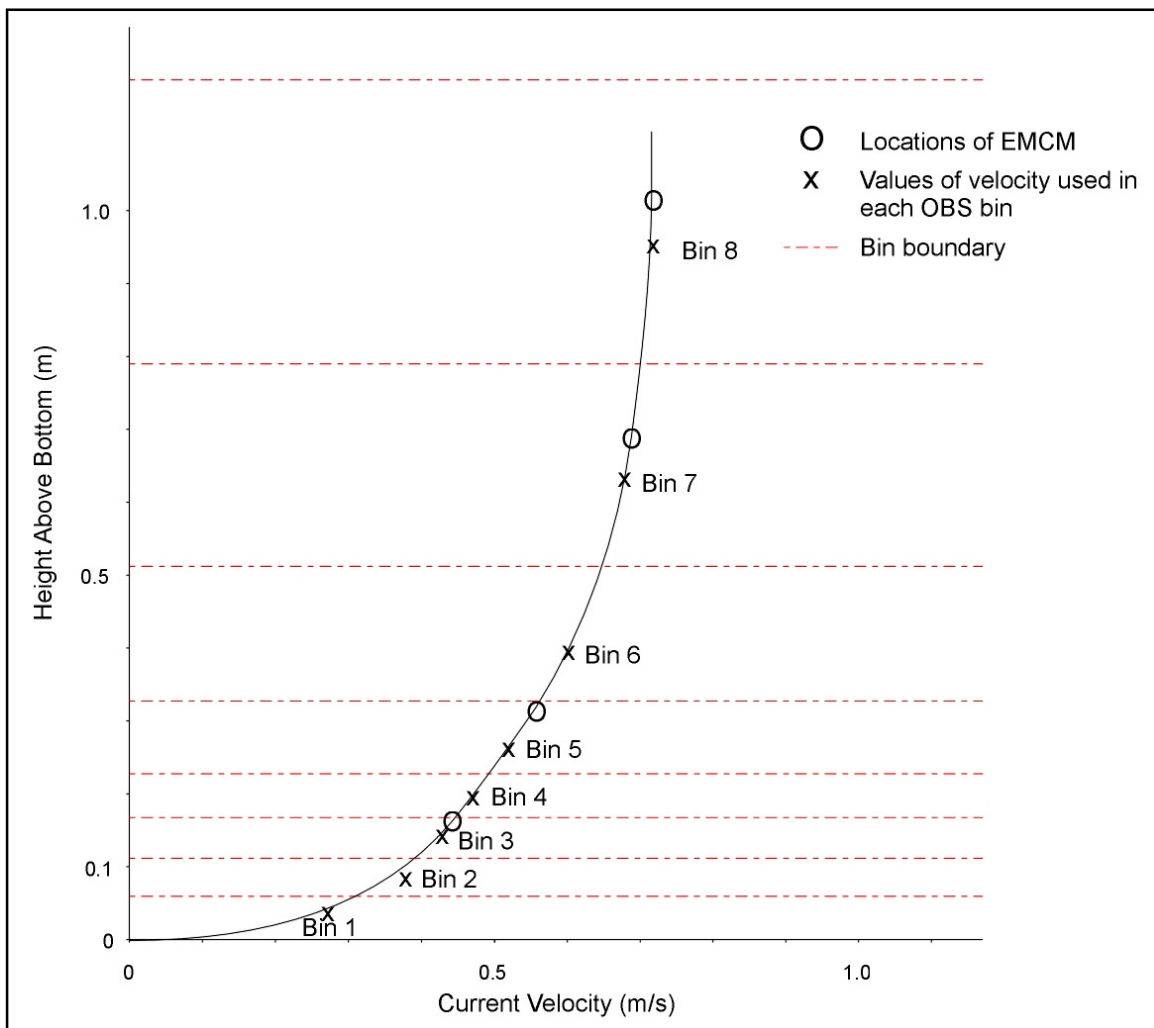

Figure 4. Interpolation of EMCM to OBS bin locations

in the summation that provides the vertically integrated flux rate. This usually includes the upper bin, and often several bins below this.

Bins below the lowest EMCM must also be treated separately. As previously stated, there are inherent difficulties in placing instruments near the bottom during storms. Inserting EMCM and OBS into the wave boundary layer may not be feasible. Therefore, methods must be developed for interpolating current between the lowest EMCM and the sediment bed/water interface to provide a velocity value for each bin below the lowest EMCM. Three options for this estimate are provided in Figure 5 and represent

a. constant velocity between lowest EMCM and sediment bed/water interface,

b. constant velocity from the lowest EMCM to the wave boundary layer and linear decrease in velocity from top of the wave boundary layer to zero velocity at the interface,

c. quadratic decrease in velocity from the lowest EMCM to zero at the interface.

Option *a* will overestimate velocity in the wave boundary layer because velocity is, by definition for viscous flow, zero at the interface. However, this overestimate of velocity may be offset by the underprediction of concentration in the bottom bin. For estimating transport from the STORM data, method *b* was employed.

After velocity/concentration time series are developed for each bin, time-averaged unit longshore transport is estimated for each bin:

$$q_{bin} = \frac{1}{N} \sum_{i=1}^{N} C_i u_i h_{bin} \qquad (1)$$

where N is the number of measurements in the deployment, C is the concentration, h_{bin} is the height of the bin, u is the longshore current, and q_{bin} is the time-averaged longshore transport through the bin in kg/m/hr. The transport rates for each bin are then summed to provide an estimate of the longshore transport per meter width over the entire water column

$$q_i = \sum_{bin=1}^{m} q_{bin} \qquad (2)$$

where m is the number of bins being used to calculate the vertically integrated transport rate and q is the vertically integrated longshore transport rate in g/m/s at offshore location i.

INTEGRATION ACROSS SURF ZONE: For the STORM measurements, transects of data collection stations were performed in a manner such that water level and longshore currents remained nearly constant across the surf zone. By collecting data in this manner, it is possible to estimate the integrated longshore transport of sediment across the surf zone for a particular period of time. The integrated longshore sand transport rate is estimated by first assuming that the transport measured at a particular station is representative of transport within certain limits of space band time. More precisely, the integrated estimate assumes that longshore transport
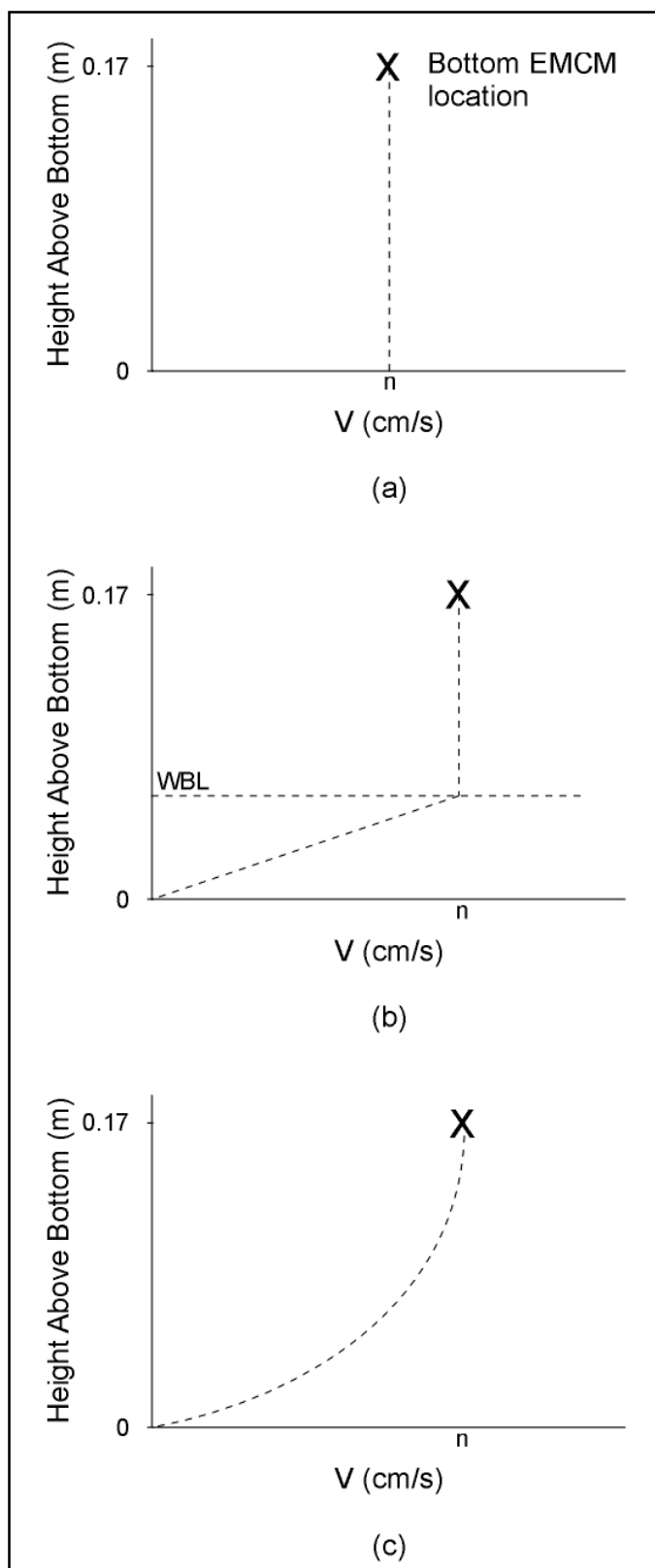
Figure 5. Methods for approximating velocity
below the lowest EMCM

measured at a particular data-collection station is spatially representative of transport at that cross-shore position plus and minus some distance (approximately ±17 m for the STORM experiment). Additionally, the integrated estimate assumes that longshore transport at a particular station is representative of transport over a particular period (approximately 4 hr for the STORM experiments).

The form of spatial integration of the measured data is represented in the diagram in Figure 6. From the notation in Figure 6, the integrated longshore sand transport, Q, can be represented as

$$Q = \sum_{i=1}^{N} q_i b_i \tag{3}$$

where,
q_i = vertically integrated unit transport rate, units of mass/unit width/time
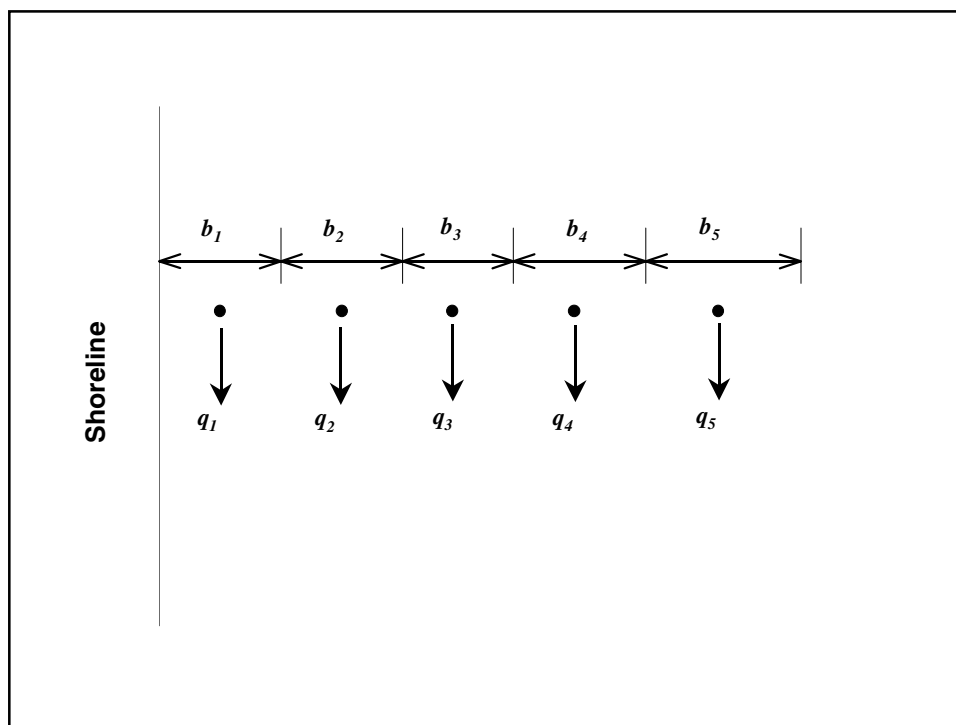b_i = width of representative bin associated with q_i

Figure 6. Schematic for integrated longshore transport calculation

SUMMARY: Longshore sand transport can be estimated with reasonable accuracy if measurements are made on the appropriate spatial and temporal scales and data are properly processed to eliminate spurious signals and background concentration. In addition, the user must have a reasonable understanding of the limitations of the instruments under the conditions where they are employed. The methods outlined in this CETN offer one tested approach to measuring longshore sand transport. The instruments and data collection system proved to be robust and

reliable in a high-energy environment. Significant post-processing of the resulting large volumes of data was required to provide estimates of transport.

ADDITIONAL INFORMATION: Questions about this CETN can be addressed to Dr. Joseph Z. Gailani (601-634-4851, Fax 601-634-4314, email: *gailanj@wes.army.mil)* or Mr. S. Jarrell Smith (601-634-4310, Fax 601-634-4314 email: *smithj2@wes.army.mil).*

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